Mississippi State
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Center for Air Sea Technology

FINAL REPORT
MODELING THE SANTA BARBARA CHANNEL USING REALISTIC OPEN BOUNDARY CONDITIONS AND WINDS UNDER OFFICE OF NAVAL RESEARCH RESEARCH GRANT N00014-97-1-0525

by

Lanny Yeske , James Corbin,
David Dietrich, and Avichal Mehra

Technical Report 6-98
30 September 1998

Mississippi State University Center for Air Sea Technology
Stennis Space Center, MS 39529-6000

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1.0 INTRODUCTION

The Mississippi State University Center for Air Sea Technology (CAST) was awarded Research Grant Number N00014-97-1-0525 by the Office of Naval Research (ONR) for Modeling the Santa Barbara Channel Using Realistic Open Boundary Conditions and Winds during the period of 1 April 1997 through 30 September 1998. This report responds to the requirement to provide a final technical report upon completion of the grant. The total amount of the research grant was $190,000.

Section 2.0 provides details on the research proposed by Mississippi State University and the accomplishments. Section 3.0 provides a list of resultant publications and, finally, Section 4.0 summarizes CAST presentations and demonstrations.

2.0 MSU PROPOSED RESEARCH AND ACCOMPLISHMENTS

2.1 Introduction and Background Information

The preliminary DieCAST numerical experiments in the Santa Barbara Channel (SBC), together with observations, indicated that the California Current system and summertime wind forced coastal current may have significant impact on the SBC circulation. There was also a significant impact from watermass transformations within the California Bight. At a November 1996 SBC ONR Quality Review Board meeting, MSU CAST showed preliminary results, including animations, from the SBC using DieCAST. By varying the coastal inflow conditions over a reasonable range, the results included some of the main observed regimes. We also showed animations from the California Current (CC) model results developed in collaboration with Naval Postgraduate School (NPS).

2.2 Proposed Research

The goal of this research was to realistically model the SBC, and lead to a nowcast/forecast capability in the region. This required accurate high resolution winds and open boundary conditions, and a model having adequate representation of the surface mixed layer dynamics; good accuracy for the dominant Coriolis and internal wave propagation terms; realistically small numerical dissipation and dispersion; and a good representation of the bottom boundary layer especially in shallow coastal regions.

Keen and Glenn, using the Princeton Ocean Model, found that even in

strong Gulf of Mexico hurricane events, only modest improvement of results was achieved by tuning their mixed layer model parameters, while the results may be significantly improved by using higher resolution and better initial conditions. Our emphasis was to use realistic wind forcing with an existing mixing approach, and to implement a nesting approach which provided good open boundary conditions for a high resolution SBC model. Later studies might include tuning of the vertical mixing approach to improve nowcast/forecast system performance. We anticipated leveraging of this work by National Ocean Partnership Program (NOPP) studies using DieCAST; ongoing CC model studies with NPS including digital filter initialization and data assimilation; hurricane response studies in the Gulf of Mexico for Amoco; ultrahigh resolution (2 km) Lake Ontario studies in collaboration with State University of New York at Stony Brook; Western Pacific Ocean studies sponsored by Australia and New Zealand; and full Pacific Ocean and/or global studies with Dr. Jim Richman at Oregon State.

Specific tasks in this project included the following:

-Task 1: Review state-of-the-art nested grid approaches for incompressible flows, as suggested by Los Alamos scientists;

-Task 2: Implement state-of-the-art nested grid approach for SBC nesting within the CC model, both with the latest DieCAST version;

-Task 3: Implement state-of-the-art deep mixing parameterization based on the gradient Richardson number and a surface mixed layer approach based on diffusion;

-Task 4: Improve the CC model by basing its barotropic mode open boundary conditions on LANL POP model results;

-Task 5: Implement an interface to use more accurate or operational products winds for both the CC and nested SBC regions;

-Task 6: Validate the CC model in collaboration with NPS;

-Task 7: Validate the nested SBC model in collaboration with Dr. Hendershott;

-Task 8: Write a project report and submit a journal article on the findings;

-Task 9 for 1998: Extend the grid nesting technology to triply nested

domains including global and/or basin-wide models and perform validation studies;

-Task 10 for FY98: Implement and test the best available data assimilation methods; and

-Task 11 for FY98: Conduct parameter sensitivity studies towards optimization of the vertical mixing dynamics.

We first concentrated on obtaining realistic CC/SBC results under summertime conditions, because they are interesting, yet challenging, and involve a number of physical processes that future nowcast/forecast models must address, including a significant wind forced coastal current. Later, we ran some more realistic annual mean conditions augmented by annual cycle effects of mountain shadow along the SBC North rim.

2.3 Accomplishments

A modified Arakawa "a" grid SBC version of DieCAST was nested within the CC model developed in collaboration with NPS (Drs. Bob Haney and Bob Hale). Even with no sponge layers, the open SBC boundaries had little noise. The nested SBC results (1/60 degree resolution) were consistent with the lower resolution (1/12 degree) CC model results in the same region, yet rich in internal smaller-scale features that were not resolved by the coarser CC model.

Observed coastal mesoscale (40 km wide, 3-10 dynes/cm-cm) wind forcing jets were added to the CC model. These elongated jets stretched southward from main coastal headlands.Their monthly mean surface stress was ~3 dynes/cm-cm along the jet centerline. Synoptic events often give O(10) dynes/cm-cm.

Results using Hellerman summer winds, enhanced by the 3 dyne/cm-cm summer mean forcing, showed significant differences compared to results using only Hellerman winds. Thus, it may be necessary for coastal models to respond accurately to such small (40 km) scale wind jets to get realistic near-shore flow results. DieCAST responded strongly using 1/12 deg resolution.

The SBC had near zero mean through flow, because of a near balance between a local-wind-forced surface Ekman layer flow and its associated upwelling (northern SBC) and downwelling (southern SBC) distribution, and external effects from the Davidson Current and the CC system. Fluctuations away from this near balance led to the four main SBC regimes.

Based on a series of sensitivity studies with our 1/60 deg resolution SBC model nested in our 1/12 deg resolution CC model, culminated by those reported by Dietrich and Mehra (1998), we have achieved a good understanding of the SBC general circulation dynamics: the SBC general circulation is primarily an Ekman layer response to local wind forcing modified by stratification, dissipation and mixing along its perimeter, and open boundary effects from the CC.

We also have demonstrated (Dietrich and Mehra, 1998) that our SBC model nested in our CC model gives realistic mean flow as well as the main observed flow regimes reported by Harms (1996). This includes details such as a stronger eastern port time mean inflow at 50 m depth than at the surface. The main findings from this research, supported by results shown by Dietrich and Mehra (1998), include:

• Given realistic climatological wind forcing with the annual cycle specified only in the mountain shadow winds (no mountain shadow during winter), the DieCAST model gives surface and 50 m depth mean flows (Dietrich and Mehra, 1998) that are strikingly similar to observations reported by Harms (1996).

• Local wind forcing is a critical issue. A very narrow (~8 km) mountain shadow along the north rim of the SBC, together with wind turning into the channel along the south rim, as observed, is required to get realistic mean climatological westward north rim and eastward south rim flows in the SBC central basin, and the main observed fluctuations from the mean.

• The local wind forcing effects are primarily through its associated surface Ekman layer drift and upwelling distribution, rather than direct vorticity generation by wind curl.

• The upwelled CC coastal jet water tends to separate near Point Conception, and entrain some of the flow from the east along the north rim of the SBC (the rest recirculates within the SBC). It thus has substantial effects on the SBC circulation, as we correctly hypothesized earlier.

• The mean latitudinally averaged flow through the SBC is small, but oscillates. This, together with peripheral small-scale mixing eddies around the SBC rim, suggests that dissipation may play a major role in the

maintenance of the dominant central cyclonic vortex, based on simple absolute potential vorticity dynamics mechanisms. This is discussed by Dietrich and Mehra (1998). Similar mechanisms were previously discussed by Bretherton and Haidvogel (1976); Salmon, Holloway and Hendershott (1976); and Carnevale and Frederiksen (1987). This mechanism tends to maintain cyclonic flows over deep central basins of semi-enclosed seas, including the Adriatic Sea and Black Sea, as well as the SBC.

We thus expect that, given accurate synoptic winds and open boundary conditions, the DieCAST model will give accurate nowcast/forecast results. Hindcast synoptic wind inputs are presently being prepared by our collaborators at NPS, in order to have a consistent basis for comparison of the DieCAST and Princeton Ocean Models. Such comparison will lead to better understanding about coastal modeling capabilities in general (DieCAST and Princeton are quite different, so good information should result) as well as the relative strengths and weaknesses of the individual models.

In summary, surface Ekman layer flows and associated upwelling suggest that it may be necessary to accurately specify local wind forcing as well as the Davidson Current and other external effects in order to forecast the SBC beyond a few days. Direct local vorticity generation by local wind curl may be secondary. Our SBC-demonstrated nesting technology has potential for detailed coastal nowcast/forecast systems.

An impact of this research is that we now have a working one minute (approximately two kilometer) horizontal resolution, 20-vertical level, SBC Model that shows extremely detailed flow features and local wind sensitivity. In conjunction with researchers at NPS, we also have a five minute resolution CC model with which we are implementing two-way nesting with our SBC model.

The SBC model runs about one model week per cpu-hour on a Silicon Graphics Indigo 2 workstation. On a newer Pentium Pro PC, the SBC model will run more than one month per cpu day. The DieCAST model has thus been shown to have potential for high resolution shipboard coastal forecast applications.

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